



Ecosystem services provided by water birds in wetlands: A review

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ABSTRACT

Water birds have important ecological functions in wetland habitats, contributing significantly to biodiversity and providing a variety of ecosystem services. This review summarizes current research on water birds' ecological functions in wetland settings, with a focus on their contributions to providing, regulating, cultural, and supporting services. Water birds have an important role in nutrient cycling, seed dissemination, pest management, and trophic regulation, as well as functioning as bio indicators for ecosystem health. Furthermore, they have cultural and recreational significance, promoting ecotourism and traditional customs. The review focuses on how water bird populations influence wetland dynamics through foraging, migration, and nesting activities. Threats to water birds, such as habitat degradation, climate change, and human disturbance, are also examined in light of their cascading impacts on wetland functions.

Key words: Biodiversity, ecological roles, habitat management, wetland conservation

INTRODUCTION

Wetlands are extremely productive ecosystems that offer a number of vital services, such as carbon sequestration, flood control, water filtration, and vital habitat for biodiversity (Mitsch and Gosselink, 2015). As an essential part of wetland biodiversity, water birds have a significant impact on how these ecosystems are structured and function. These birds play an important role in ecological processes like seed dispersal, nitrogen cycling, and the preservation of wetland habitat diversity, all of which sustain a wide variety of other species. Birds that use aquatic environments for roosting, nesting, and foraging are generally referred to as water birds. Anseriformes (ducks, geese), Ciconiiformes (herons, egrets), Gruiformes (rails, cranes), Charadriiformes (shorebirds), and Pelecaniformes (pelicans) are among the many bird orders represented in the diverse group of

water birds. According to Gauthier and Eldridge (2018), these species have developed unique adaptations for living in and around wetlands, viz webbed feet for swimming, long bills for probing dirt, and specialized plumage for insulation in cold water conditions. Water birds play a crucial role in wetland food webs, by regulating plant and animal populations through their diverse eating preferences, which range from herbivory to piscivory (Boerner et al., 2020). The trophic dynamics of wetland ecosystems depend heavily on water birds. They serve as both food for larger predators (such as raptors and carnivorous animals) and predators, feeding on aquatic invertebrates, small fish, and vegetation (Klein, 2016). Their actions affect prey populations and preserve trophic structures, which support the ecological balance of wetlands. Large waterfowl, like ducks and geese, for instance, can change the distribution and amount of wetland vegetation, which in turn impacts the

food sources that are accessible to other creatures (Jongman et al., 2019). Apart from their feeding habits, water birds also play a role in the chemical and physical processes that occur in wetlands. Through nutrient excretion, guano deposition and sediment disturbance, their feeding and breeding activities boost biodiversity and primary productivity by redistributing nutrients within the environment (Williams et al., 2017).

Another significant ecological function of water birds is seed dissemination. In order to promote the connectedness of wetland plant communities and aid in the colonization of new habitats, several species, particularly waterfowls transport seeds from one location to another (Van der Valk and Davis, 2018). By guaranteeing the survival of plant species that depend on water birds for dispersal, this activity can contribute to the preservation of plant variety and ecosystem stability in wetlands (Guillemain et al., 2017). Furthermore, certain water bird species take part in behaviors that physically change wetland environments, like changing plant growth or establishing open water areas, which might help other wildlife species (Raab et al., 2020).

Because of their sensitivity to environmental changes, water birds also serve as bio indicators of the health of wetland ecosystems. Since they are frequently the top predators in wetland food webs, their distribution and abundance can be used to gauge the habitat's general health, including pollution levels, water quality, and food resource availability (Niemelä et al., 2019). Water bird population monitoring over an extended period can yield important information about how anthropogenic activities, habitat degradation, and climate change affect wetland ecosystems (Hollis et al., 2021). For example, decreases in water bird populations frequently indicate the beginning of habitat loss or wetland eutrophication, both of which have detrimental effects on ecosystem functioning (Liu et al., 2018).

Water birds face many risks despite their ecological importance, most of which are caused by human activity. One of the main reasons why water bird populations are declining worldwide is wetland

degradation brought on by drainage, urbanization, and agriculture (Sutherland et al., 2017). Another significant issue is climate change, which has an impact on many species' food availability, mating success, and migration timing (Van der Jeugd et al., 2018; Zhang et al., 2020). Therefore, the preservation and restoration of wetland habitats, as well as the control of environmental stressors that affect wetland ecosystems, are closely related to the conservation of water birds.

The aim of this review is to present a thorough overview of the various functions that water birds perform in wetland environments. In addition to analyzing their potential as bio indicators of wetland health, it investigates their roles in trophic dynamics, nitrogen cycling, habitat alteration, and seed distribution. It covers the different risks that water birds face and the significance of conservation measures to guarantee both their survival and the sustainability of the wetlands they call home. Through this investigation, we hope to draw attention to the vital role that water birds play in preserving the biological integrity of wetlands and the necessity of protecting them in view of the continuous environmental threats.

OVERVIEW OF WETLAND ECOSYSTEM

According to Mitsch and Gosselink (2015), wetlands are distinct, dynamic ecosystems that support a wide range of species, perform vital ecological tasks, and varied ecosystem services. They are described as regions that are constantly or seasonally saturated with water and that are home to a range of vegetation types, such as floating, submerged, and emergent plants (Dugan, 1990). From the Arctic tundra to tropical regions, wetlands can be found in every temperature zone. They range in size from tiny ponds to vast marshes, bogs, and estuaries. The anoxic conditions caused by the wet soils that define these habitats have an impact on the kinds of plants and animals that can flourish there. Wetlands are classified into several categories based on their hydrology, vegetation, and ecological functions, with two major types being freshwater wetlands (e.g., marshes, swamps, and bogs) and coastal wetlands (e.g., estuaries, mangroves, and tidal flats) (Keddy, 2010).

They are often classified further into palustrine, lacustrine, and riverine wetlands, depending on their connection to water bodies such as lakes or rivers (Cowardin et al., 1979). The hydrological and biogeochemical characteristics of wetlands create a productive environment for diverse species, making them one of the most biologically rich ecosystems on earth (Mitsch & Gosselink, 2015). Wetlands often act as transition zones between terrestrial and aquatic habitats, supporting a high degree of biodiversity, including a variety of plant species, invertebrates, fish, amphibians, and birds (Davidson, 2014). In particular, water birds are key components of wetland biodiversity and play an important role in shaping the structure and function of these ecosystems.

Water birds participate in a variety of ecological processes that enhance ecosystem resilience and productivity, water birds are essential to the health and operation of wetland ecosystems. Water birds can improve primary productivity and preserve water quality by transferring nutrients within and between aquatic and terrestrial environments through their foraging activities (Gunnarsson et al., 2018). Furthermore, a variety of water bird species serve as seed dispersers, which promotes plant colonization and preserve the diversity of wetland vegetation (Wenny et al., 2016). As top predators in wetland food webs, they aid in controlling fish and aquatic invertebrate populations, which can prevent ecological imbalances and manage pest outbreaks (Jefferies et al., 2017). By upsetting sediment layers while feeding, water birds also influence sediment dynamics by facilitating the release of nutrients and oxygen that are advantageous to wetland plants (Batzer and Boix, 2016). Furthermore, water birds are important bio indicators; variations in their numbers and habits can serve as early warning signs of environmental deterioration and frequently indicate changes in the health of wetland ecosystems (Ma et al., 2020). Water birds serve cultural ecosystem services in addition to ecological ones by offering chances for leisure, bird watching, and environmental education, all of which can encourage conservation and public participation. Because of their diverse functions,

water bird populations must be protected in order to preserve biodiversity and the numerous ecosystem services that wetlands offer.

Kumar et al. (2022) highlighted the ecological significance of urban green spaces as waterbird refuges by reporting 124 bird species at Delhi's National Zoological Park, New Delhi. Odisha surveys, like the one by Patnaik et al. (2023), found 46 species close to Govt. (Auto.) College, Angul, demonstrating how urban and semi-urban wetlands support bird biodiversity in spite of human-induced stressors. 38 bird species were recorded in another study conducted in Paradip, Odisha, highlighting the necessity of conservation measures in port cities where wetland ecosystems are at risk (Mohanty and Das, 2024). Additionally, Singh and Verma (2021) observed the Red-Wattled Lapwing's adaptation to urban nesting sites in Dehradun, illustrating both the resilience of some water bird species and the urgent need to protect wetlands amid urban expansion. Together, these studies reinforce the vital connection between wetland conservation and sustaining the essential ecosystem services provided by water birds.

Ecological functions of wetlands

Important ecological services including carbon storage, flood control, water filtering, and wildlife habitat are all provided by wetlands as illustrated in Fig. 1. By capturing pollutants, sediments, and nutrients before they enter bigger water bodies, wetlands may filter and purify water, which is one of its most crucial roles (Gosselink and Turner, 2009). This role is especially crucial for minimizing the consequences of water pollution from urban runoff and agriculture, as well as for lowering the eutrophication of freshwater systems. Additionally, by collecting surplus water during times of heavy rainfall or snowmelt, wetlands serve as natural flood barriers (Mitsch and Gosselink, 2015). By absorbing and retaining carbon dioxide from the atmosphere, wetlands also act as carbon sinks. Wetland soils, especially peat lands, are important for mitigating climate change because they store a lot of carbon over extended periods of time (Worrall et al., 2018).

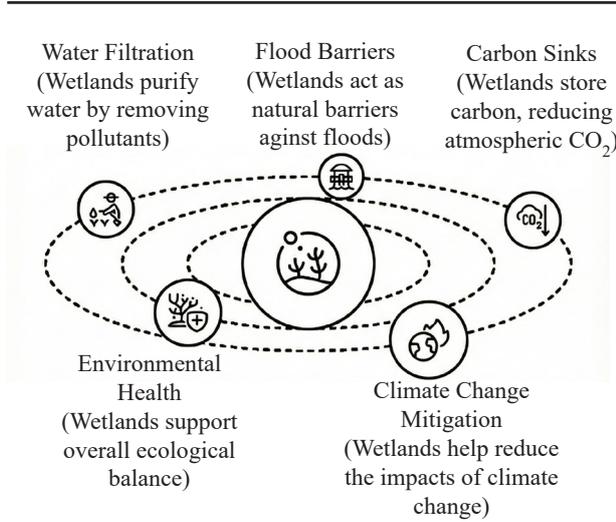


Fig. 1. Vital roles of wetlands in the ecosystem

Additionally, wetlands are essential to preserving biodiversity. Many species, especially migratory water birds, use them as nesting, feeding, and resting grounds. From grazing in nutrient-rich wetland waters to nesting in marshes and swamps, many water bird species depend on wetlands throughout their life cycles. High degrees of endemism are also supported by wetlands, as certain species have adapted to the particular environmental circumstances found in the wetlands (Batzer and Boix, 2016). Wetlands are therefore protected by international agreements like the Ramsar Convention, which acknowledges the value of wetlands for the preservation of water birds and other species, and are regarded as hotspots for biodiversity (Ramsar Convention Secretariat, 2013).

Wetland degradation and threats

Wetlands are among the most endangered habitats in the world, despite their ecological significance. Urbanization, agricultural growth, and industrial development are some of the causes that contribute to wetland loss and degradation (Davidson, 2014). Large wetland areas have been destroyed due to drainage for agriculture and land reclamation, especially in temperate regions where wetlands have been turned into cropland or urban development (Keddy, 2010). Along with disrupting the biodiversity of these habitats, the conversion of

wetlands for human use results in the loss of vital ecosystem services including flood control and water filtration.

Wetland ecosystems are also seriously threatened by climate change. Wetland hydrology and plant communities are being impacted by rising temperatures, changed precipitation patterns, and a rise in the frequency of extreme weather events (Zhang et al., 2020). The distribution of wetland species, such as water birds that depend on certain wetland conditions for breeding and foraging, may be impacted by shifts in the timing and duration of seasonal water levels. Furthermore, the sustainability of wetlands may be further threatened by higher evaporation brought on by rising temperatures, which could worsen water scarcity in some areas (Batzer and Boix, 2016). Wetlands are also seriously threatened by pollution from sewage, industry, and agricultural runoff. Eutrophication, which lowers oxygen levels and promotes the growth of toxic algal blooms, can result from nutrient pollution, especially those caused by nitrogen and phosphate (Smith et al., 2016). Water bird populations that depend on aquatic invertebrates and plants for sustenance are also negatively impacted, as is the food chain (Liu et al., 2018).

Wetlands confront more subtle concerns than hydrological change and loss of area. The diversity and number of water birds are decreased by invasive species, which include both plants (like smooth cordgrass and water hyacinth) and predators (like non-native animals). These species also disrupt the structure of habitats, decrease or alter the availability of food, and increase nest predation (Zhao et al., 2018; Nordstrom, 2020). Growing amounts of micro plastic pollution in wetland sediments have also been reported in recent research; these plastics can alter the structure of microbial communities, interfere with plant root function, and eventually decrease wetlands' ability to absorb carbon (Wang et al., 2022; Liu et al., 2023). Additionally, freshwater hydrophytes are being stressed by saline intrusion brought on by sea level rise or changed freshwater inflows, which is also changing the makeup of aquatic invertebrates and

vegetation. These changes have an impact on water bird nesting and foraging. Emerging risks also come from chemical contaminants (heavy metals, endocrine disruptors, and medications) and shifting water chemistry (from increased nutrients plus changed salinity), which frequently work in concert (Smith et al., 2016; Zhang et al., 2020). The cumulative effect of these challenges, especially in light of the accelerated climate change, may seriously impair ecosystem functions and put many water bird species in threat that depend on wetlands.

DIVERSITY AND FUNCTIONAL CLASSIFICATION OF WATER BIRDS

Diversity of taxa

Numerous species of water birds are adapted to a variety of wetland habitats, demonstrating the taxonomic richness of this group. They fall under the following general categories:

- i. Ducks, geese, and swans are members of the Anseriformes family, which is mostly herbivorous or omnivorous and feeds on water plants, seeds, and invertebrates.
- ii. Charadriiformes family: This group includes gulls and shorebirds. These animals are frequently piscivorous or insectivorous, helping to regulate insect populations and feeding on tiny fish.
- iii. The family Ciconiiformes includes carnivorous animals such as herons, egrets, and ibises that eat fish, amphibians, and invertebrates.

Functional classification

Primary producers

Although they are uncommon, some water birds feed aquatic plants with their droppings, which helps with primary production.

Primary consumers

Herbivorous water birds, like several duck species, impact the dynamics of plant communities by consuming aquatic plants and debris.

Secondary consumers

Many shorebirds and other insectivorous and

omnivorous species help regulate insect populations and aid in the cycling of nutrients.

Tertiary consumers

As apex predators in their own niches, carnivorous animals such as kingfishers and herons control fish and amphibian populations.

Seed dispersers

A variety of water birds aid in the spread of seeds, especially those of aquatic plants, which promotes plant diversity and regrowth.

Nutrient cyclers

Water birds are essential nutrient cyclers, moving nutrients from one trophic level to another and increasing ecosystem productivity through their feeding and excretion.

Bio-indicators

Kingfishers, which are piscivorous and frequently act as bio indicators of wetland quality because of their sensitivity to environmental changes, belong to the Coraciiformes family.

Ecological roles

Beyond their feeding habits, water birds have a variety of ecological responsibilities.

Habitat engineers

Some species, like some ducks, build nesting places that change the wetland's physical composition, which affects the amount of habitat available to other species.

Bio-indicators

Water birds are bio indicators that show the health of wetland ecosystems because of their sensitivity to environmental changes. Water bird population declines frequently indicate worsening habitat conditions.

Cultural and economic significance

In many cultures, water birds are highly valued culturally, and through hunting and bird watching, they support local economies.

Conservation status

Water bird species' conservation status

varies around the world, and many are threatened by hunting, pollution, habitat loss, and climate change. The wetland conservation is crucial for safeguarding water bird populations, according to international agreements like the Ramsar Convention. To guarantee these species' existence and the wellbeing of wetland ecosystems, efforts are made to restore habitat, reduce pollution, and implement sustainable management techniques.

ECOLOGICAL FUNCTIONS OF WATER BIRDS IN WETLAND ECOSYSTEMS

Water birds contribute to the biological balance and well-being of wetland habitats through a variety of roles. Their behaviors affect a number of ecological processes, such as species interactions, habitat architecture, and nutrient cycling.

Energy flow and nutrient cycling

The cycling of nutrients in wetland habitats depends on water birds. They aid in the movement of nutrients between trophic levels by consuming a wide range of species, such as tiny fish, invertebrates, and aquatic plants. By returning nutrients to the soil and water, their excretions improve the ecosystem and aid in primary production. Wetland ecosystems become more productive as a result of this process, ranking among the planet's most biologically productive areas.

Dynamics of vegetation and seed dispersal

Numerous water bird species aid in the establishment of aquatic and riparian plants by dispersing seeds. Through eating and subsequent defecation, the fruits and seeds they consume are carried to new sites. This seed movement influences the structure and succession of plant communities by encouraging plant diversity and the growth of vegetation in different areas of the marsh.

Habitat structure and engineering

Water birds can act as habitat engineers, modifying their environment in ways that create or alter habitats for other species. For instance, the feeding activities of certain water birds can

influence the growth patterns of aquatic vegetation, affecting the structure of the habitat. Additionally, their nesting behaviors can create microhabitats that support a variety of other organisms, contributing to the overall biodiversity of the wetland.

Bio-markers of the health of ecosystems

The sensitivity of water birds to environmental changes makes them useful bio indicators of the health of wetlands. Changes in habitat, contaminants, and water quality can all be indicated by fluctuations in water bird numbers. Keeping an eye on these populations can help guide conservation and management plans and offer important insights into the ecological health of wetlands.

Regulation of disease and pest control

By consuming insects and other invertebrates that can harm marsh flora, certain species of water birds help control pests. Water birds contribute to the preservation of the ecosystem's equilibrium by controlling these populations. Additionally, because they have an impact on disease vector populations, their existence may have an impact on the prevalence of diseases inside the wetland.

Contributions to culture and the economy

Water birds have cultural and economic value in addition to their ecological duties. They are essential to many customs and cultural behaviors, particularly in societies that depend on wetlands for their life and nutrition. Since bird watching is a common pastime in wetland areas, water birds economically support ecotourism. This creates revenue and increases understanding of the value of preserving wetlands.

THREATS TO WATER BIRD POPULATION AND WETLAND ECOSYSTEM

Despite playing a vital role in wetland ecosystems, water birds are threatened in many ways, endangering both their numbers and the health of the marshes they live in. Anthropogenic activity, climate change, and environmental degradation are the main causes of these hazards. Designing

successful conservation plans and guaranteeing the long-term sustainability of these habitats depend on an understanding of the main risks to both water birds and wetland ecosystems.

Degradation and loss of habitat

The biggest danger to water bird populations is probably habitat loss. Due to their extreme vulnerability to human activity, many wetlands have been drained or transformed for infrastructure, urbanization, or agricultural purposes. Important habitats for water birds to breed, feed, and nest have been destroyed as a result of wetland drainage for agricultural growth. Water bird populations suffer when wetlands are lost because there are fewer food sources, safe nesting grounds, and migratory stops available (Davidson, 2014). Invasive species, pollution, and hydrological changes can also cause wetland deterioration. Wetlands' natural water levels can be changed by dams, irrigation systems, and urban development, which can impact the flora and water birds' access to food (Keddy, 2010). The entire wetland ecology may eventually be impacted as a result of the disturbance of plant and animal groups.

Climate change

The threat posed by climate change to wetland habitats and the animals that rely on them is intricate and multidimensional. Wetland hydrology is already being impacted by changes in temperature, precipitation patterns, and the frequency of extreme weather events. Many water bird species that rely on particular water levels for nesting may experience disruptions in their breeding cycles due to rising temperatures that can change the timing and severity of wetland flooding and drying cycles (Van der Jeugd et al., 2018). Furthermore, in some areas, water scarcity can be made worse by greater evaporation brought on by warmer temperatures leading to reduction of wetland areas. Because many fish and aquatic invertebrate species are sensitive to temperature fluctuations, climate change may potentially result in changes in the availability of food sources (Zhang et al., 2020). Water birds may have to

relocate or adjust their eating habits as a result of these shifts in the availability of food, which could result in population decreases.

Pollutants and contaminants

Water bird populations and wetland ecosystems are seriously threatened by pollution. Numerous pollutants, such as heavy metals, pesticides, medications, and nutrients (phosphorus and nitrogen), are introduced into wetland waterways via urban sewage, industrial discharges, and agricultural runoff. Eutrophication, which lowers oxygen levels and encourages the growth of toxic algal blooms, can result from an excess of nutrients from agricultural runoff (Smith et al., 2016). These blooms have the potential to produce hypoxic conditions, which would destroy aquatic species and decrease the amount of food available to water birds. Furthermore, pollutants like pesticides and heavy metals build up in the food chain and can harm water bird populations. Birds that consume tainted water or food may experience immune system weakness, infertility, or even death. These compounds can negatively impact entire populations through long-term bioaccumulation, which lowers species variety and richness in wetland habitats (Zhang et al., 2020).

Invasive species

Wetland ecosystem biodiversity is seriously threatened by invasive species. The ecological balance of wetland ecosystems can be upset by non-native species that outcompete or prey on local plants and animals. For instance, native plant species that are crucial for water bird foraging and breeding may be displaced by invasive plants like *Typha* (cattails) and *Phragmites australis* (common reed), which can take over wetland vegetation (Keddy, 2010). The thick monocultures that these invasive plants frequently create limit the variety of habitats available to water birds.

Hunting and overharvesting

Other hazards to water bird populations include hunting and overharvesting, especially in areas where hunting waterfowl is commercially or culturally significant. Even while hunting laws have been put in place in many nations to manage

water bird populations and stop overhunting, fragile species are still at risk from illicit hunting and uncontrolled harvests. Population reductions can result from overhunting, especially during migratory times, especially for species that are already under stress from the environment or have sluggish rates of reproduction (Van der Jeugd et al., 2018). Hunting can also change how water birds use wetland habitats and interfere with their migration patterns. Hunting pressure may cause some water birds to avoid particular locations, which can result in the loss of vital habitats and the displacement of entire populations (Sutherland et al., 2017).

Inadequate conservation and management efforts

In order to keep wetland ecosystems healthy and in balance, water birds are essential. They serve as bio indicators of ecosystem health and aid in seed dissemination, nutrient cycling, and pest control. Nevertheless, conservation and management initiatives for water birds and their habitats continue to be inadequate and dispersed, despite their ecological significance.

CONSERVATION AND MANAGEMENT OF WATER BIRDS AND WETLANDS

Habitat protection and restoration of protected areas

Important habitats are protected when wetlands are designated as national parks, Ramsar areas, or reserves (Ramsar Convention Secretariat, 2016). Restoration Projects: Restoring habitat quality and hydrological functions is facilitated by rewetting drained wetlands and eliminating invasive species (Zedler, 2000).

Sustainable land use and buffer zones for pollution control

Planting vegetation buffers around wetlands lowers nutrient runoff. Regulation: Reducing contamination is aided by the implementation of laws governing the use of pesticides and pollutants.

Climate change adaptation strategies

Wetland connectivity Restoring and maintaining habitat corridors makes it easier for

animals to migrate in response to changes in the climate. Managed Realignment: Coastal habitats are preserved by permitting wetlands to move inland when sea levels rise (Craft et al., 2009).

Research and monitoring

Early indicators of ecosystem stress are found by routine population and breeding success monitoring (Gregory et al., 2004). Citizen Science: Data collection and awareness are improved when communities get involved in bird watching and reporting. Research: Adaptive management is informed by the ecology and response to threats of species. Sustainable Agriculture: Reducing pollution and habitat loss by promoting wetland-friendly farming methods.

Community engagement and education

Awareness Programs: Educating the public about the ecological value of water birds and wetlands fosters stewardship. Involving Local Communities: Incorporating traditional knowledge and providing incentives encourages sustainable use.

CASE STUDIES

The United States' Chesapeake Bay

Numerous water bird species, such as colonial breeding herons and migratory ducks, can be found in the Chesapeake Bay (Fig. 2). Water bird numbers and water quality have increased as a result of restoration initiatives that emphasize habitat improvement and nutrient reduction (Kemp et al., 2005).



Fig. 2. Chesapeake Bay in United States (Chesapeake Bay Foundation)

Bangladesh and India's Sundarbans mangrove forest

The Sundarbans, which are home to a distinctive group of water birds, are threatened by both human exploitation and sea level rise as given in Fig. 3. To preserve biodiversity, conservation programs integrate community-based management with habitat protection (Giri et al., 2015).



Fig. 3. Mangrove forest (<https://whc.unesco.org/en/list/798/>)

Botswana's Okavango delta

During seasonal floods, this inland delta is home to significant colonies of water birds. Despite mounting pressures, ecological integrity has been preserved because of sustainable tourism and stringent wetland restrictions (McCarthy et al., 2000) as illustrated in Fig. 4.



Fig. 4. Botswana's Okavango delta (<https://www.tripsavvy.com/guide-to-okavango-delta-in-botswana-1454194>)

CONCLUSION

Water birds are essential to the structure, function, and biodiversity of wetland ecosystems in a variety of ways. Due to their varied adaptations, they may take advantage of a variety of wetland habitats across the globe, making significant contributions to ecosystem functions such as trophic regulation, vegetation dynamics, seed dissemination, and nutrient cycling. Often referred to as the “kidneys of the landscape,” wetlands depend on these birds to maintain ecological services that enhance human well-being and biodiversity. Wetlands and water birds are interdependent, which emphasizes how delicate and complicated these ecosystems are. However, growing anthropogenic pressures such as habitat loss, pollution, climate change, and human disturbance are endangering water birds' ability to survive. The integrity of the entire wetland ecosystems that the water birds maintain is in danger, in addition to the birds themselves. As a result, conservation and management initiatives need to take an integrated approach that incorporates community involvement, strict monitoring, pollution prevention, habitat preservation, and climate adaptation. For these migratory and resident species to be protected, international collaboration is essential, as demonstrated by frameworks like the Ramsar Convention, migratory bird treaties, and regional conservation programs. The complex ecological roles of water birds, their reactions to new challenges, and creative conservation techniques should be the main topics of future studies. The only way we can guarantee the survival of water birds and the priceless wetland habitats they live in is by persistent scientific measures, policy changes and public commitment.

RESEARCH NEEDS

Even though the ecological importance of water birds in wetland ecosystems is becoming more widely acknowledged, there are still a number of unanswered questions regarding the complete spectrum of ecosystem services that these birds provide. Current understanding can be expanded upon in the following important areas by future research.

Quantification of ecosystem services

The services that water birds offer, including nutrient cycling, seed dissemination, pest control, and cultural values, are primarily qualitatively described in research. Quantitative evaluations of these services are urgently needed, nevertheless. Policymakers would be better able to incorporate avian contributions into wetland management and conservation planning if standardized methods for measuring and commercializing these services were developed.

Long-term and large-scale monitoring

In order to comprehend how the ecological services that water birds provide alter with climate, land-use change, and wetland degradation, longitudinal studies across several biogeographic zones are crucial. AI-driven picture analysis, citizen science, and satellite tracking might greatly improve data gathering and monitoring activities.

Role in climate change mitigation and adaptation

Priority should be given to studies on the ways in which water birds support climate resilience through their roles in wetland restoration, carbon sequestration (for example, through vegetation dynamics), and temperature adaptability. It is also crucial to look at how water bird populations and their ecological roles are impacted by climate change.

Interdisciplinary approaches

Working together, ornithologists, ecologists, economics, and social scientists can improve our comprehension of the functions of water birds. For example, combining contemporary scientific methods with local populations' traditional ecological knowledge (TEK) might result in comprehensive conservation plans.

Policy integration and conservation frameworks

Future research should concentrate on converting ecological discoveries into workable policies in order to close the gap between science and policy. This involves incorporating the environmental services provided by water birds into

land-use planning, wetland valuation models, and international accords such as the Ramsar Convention.

Water bird-wetland interaction networks

Key species and interactions that preserve ecosystem stability and services can be identified by building intricate networks of interactions between water birds and other biotic elements (such as fish, invertebrates and plants). Keystone or umbrella species for conservation of prioritizing can also be found with the use of such networks.

Urban wetlands and novel ecosystems

Many wetlands are changing significantly as a result of growing development. How water birds are adjusting to these new ecosystems and whether they are still delivering vital ecosystem services in these changed settings should be the focus of future research.

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